Jet Propulsion Laboratory
California Institute of Technology

F Prime: An Open-Source Framework for Small-Scale Flight Software Systems

Robert Bocchino, Timothy Canham, Garth Watney,
Leonard Reder, and Jeffrey Levison

32nd Annual Small Satellite Conference
August 9, 2018
Utah State University

Introduction

- Developing flight software (FSW) is challenging
- Especially so for small spacecraft
  - Small budgets
  - Ambitious goals
- Challenges include
  - Compressed schedules (especially test)
  - Inadequate resources
  - Poorly-specified interfaces
  - Under-specified and changing requirements

Introduction

Developing Flight Software (FSW) for Small Spacecraft

- Options
  1. Develop FSW from scratch
  2. Adapt FSW from a previous mission
  3. Use a multi-mission FSW framework
- We contend that option (3) is best
  - Option (1) is too expensive and/or compromises quality
  - Option (2) can work, but it is not ideal
    - Unless FSW is designed for reuse, it is difficult to reuse
    - Developers must re-engineer it for the new mission

The F Prime FSW Framework

Overview

- Free and open-source; developed at JPL
- Tailored to small-scale systems
  - CubeSats, SmallSats, instruments
- Comprises several elements
  1. A component-based architecture
  2. A C++ framework providing core capabilities
  3. Modeling tools for specifying models and generating code
  4. A collection of ready-to-use components
  5. Testing tools for unit and integration testing
- Runs on a wide range of hardware platforms
- Runs on several OSs (e.g., Linux, Mac OS, VxWorks)

https://github.com/nasa/fprime

The F Prime FSW Framework

Architecture

- Based on components, ports, and topologies
  - **Component:** A unit of FSW function (like a C++ class)
  - **Port:** A point of connection between component instances
  - **Topology**: A directed graph of instances and connections
- Component instances
  - Communicate only through ports
  - Have no compile-time dependencies on other components
- Port connections
  - Are typed and statically specified
  - May be synchronous or asynchronous

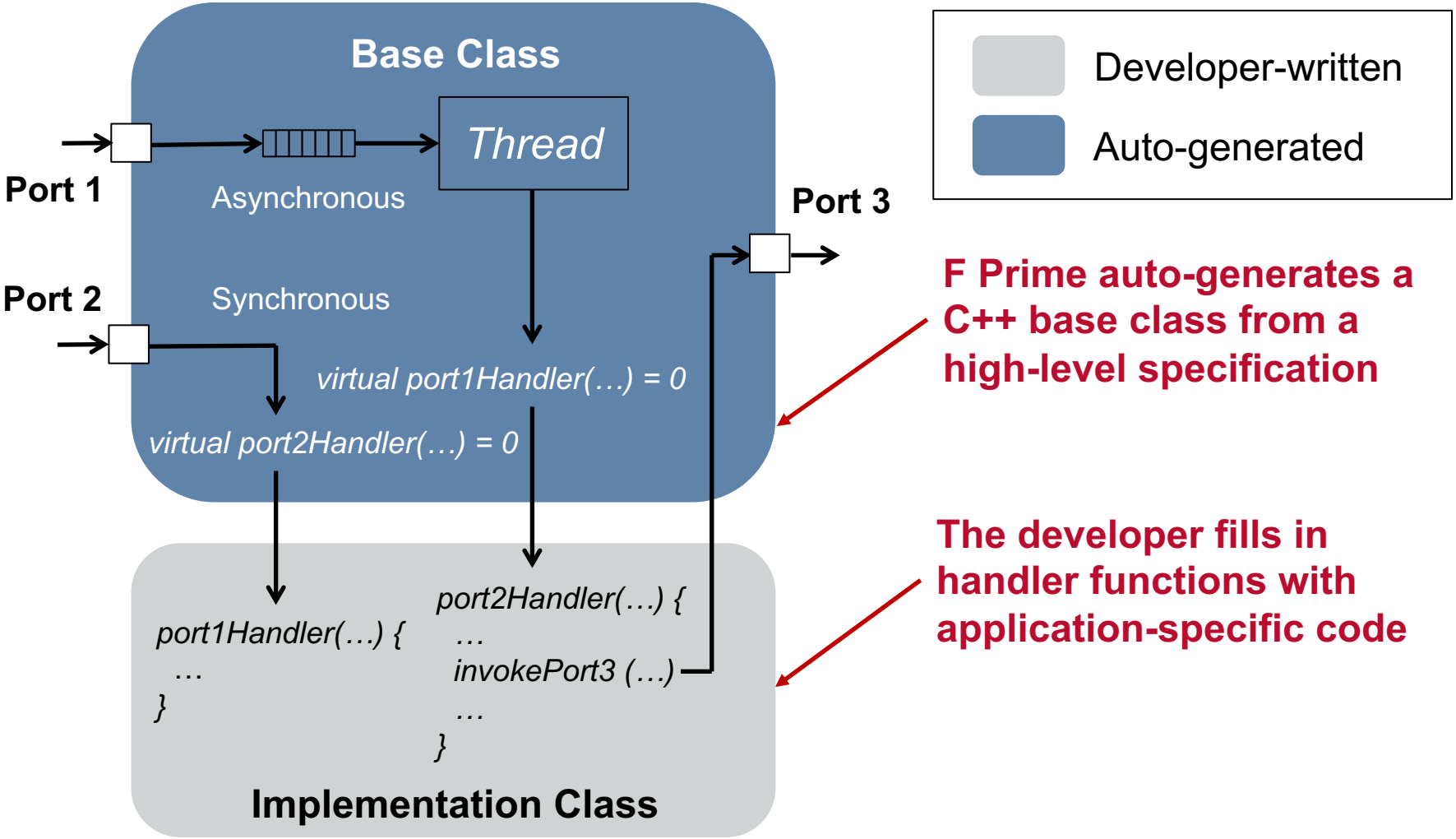
Provides structure to FSW applications

Enables automatic checking of correctness properties

Enhances reusability of FSW components

The F Prime FSW Framework

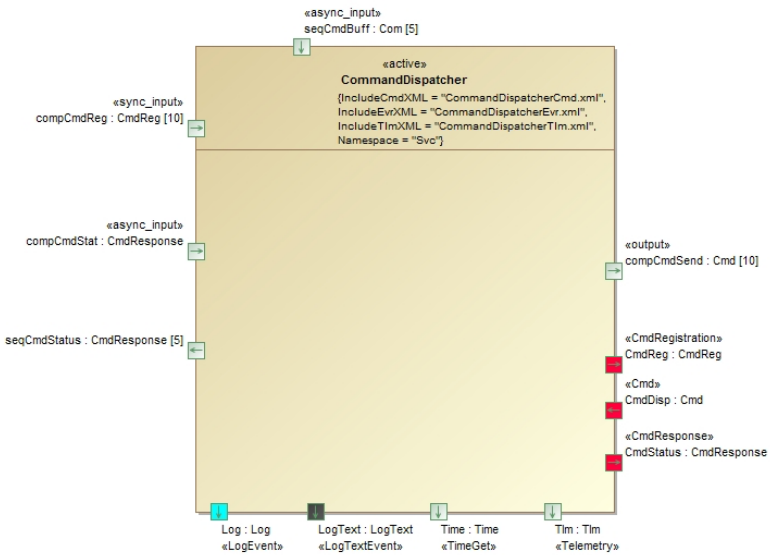
C++ Framework



The F Prime FSW Framework

Modeling and Code Generation (Components)

MagicDraw Model → **XML Specification**



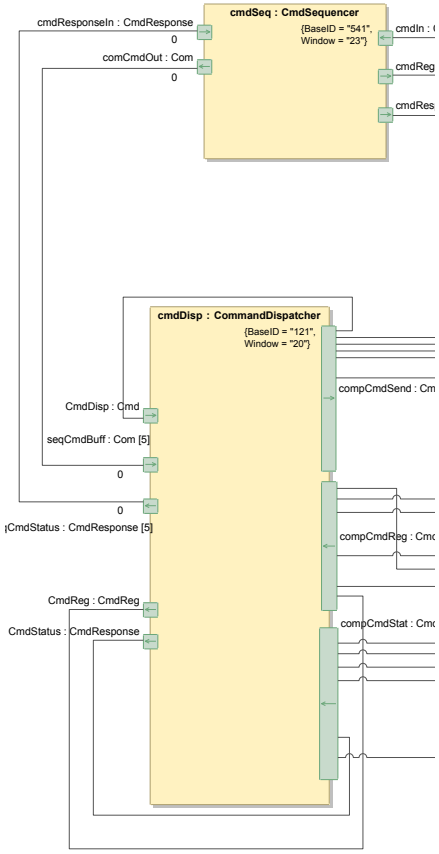

```
<component name="CmdDispatcher"
           kind="active"
           namespace="Svc">
  <import_port_type>
  Fw/Cmd/CmdPortAi.xml
  </import_port_type>
  ...
  <comment>
  A component for dispatching commands
  </comment>
  <ports>
    <port name="compCmdSend"
          data_type="Fw::Cmd"
          kind="output"
          max_number="$CmdDispatcherCommandPorts">
          <comment>Command dispatch port</comment>
    </port>
      ...
  </ports>
  ...
</component>
```

C++ Base Class **Ground Dictionaries**

The F Prime FSW Framework

Modeling and Code Generation (Topologies)

MagicDraw Model ➡ **XML Specification** ➡ **Ground Dictionaries**




```
<assembly name="Ref">
  ...
  <import_component_type>
  Svc/CmdDispatcher/CmdDispatcherComponentAi.xml
  </import_component_type>
  <import_component_type>
  Svc/CmdSequencer/CmdSequencerComponentAi.xml
  </import_component_type>
  ...
  <instance namespace="Svc"
            name="cmdDisp"
            type="CmdDispatcher"
            base_id="121"
            base_id_window="20"/>
  ...
  <instance namespace="Svc"
            name="cmdSeq"
            type="CmdSequencer"
            base_id="541"
            ase_id_window="23"/>
  ...
  <connection name="Connection37">
     <source component="cmdSeq"
             port="cmdResponseOut"
             type="CmdResponse"
             num="0"/>
     <target component="cmdDisp"
             port="compCmdStat"
             type="CmdResponse"
             num="0"/>
  </connection>
  ...
</assembly>
```

Python code for F Prime ground data system

Mission-specific ground data system formats

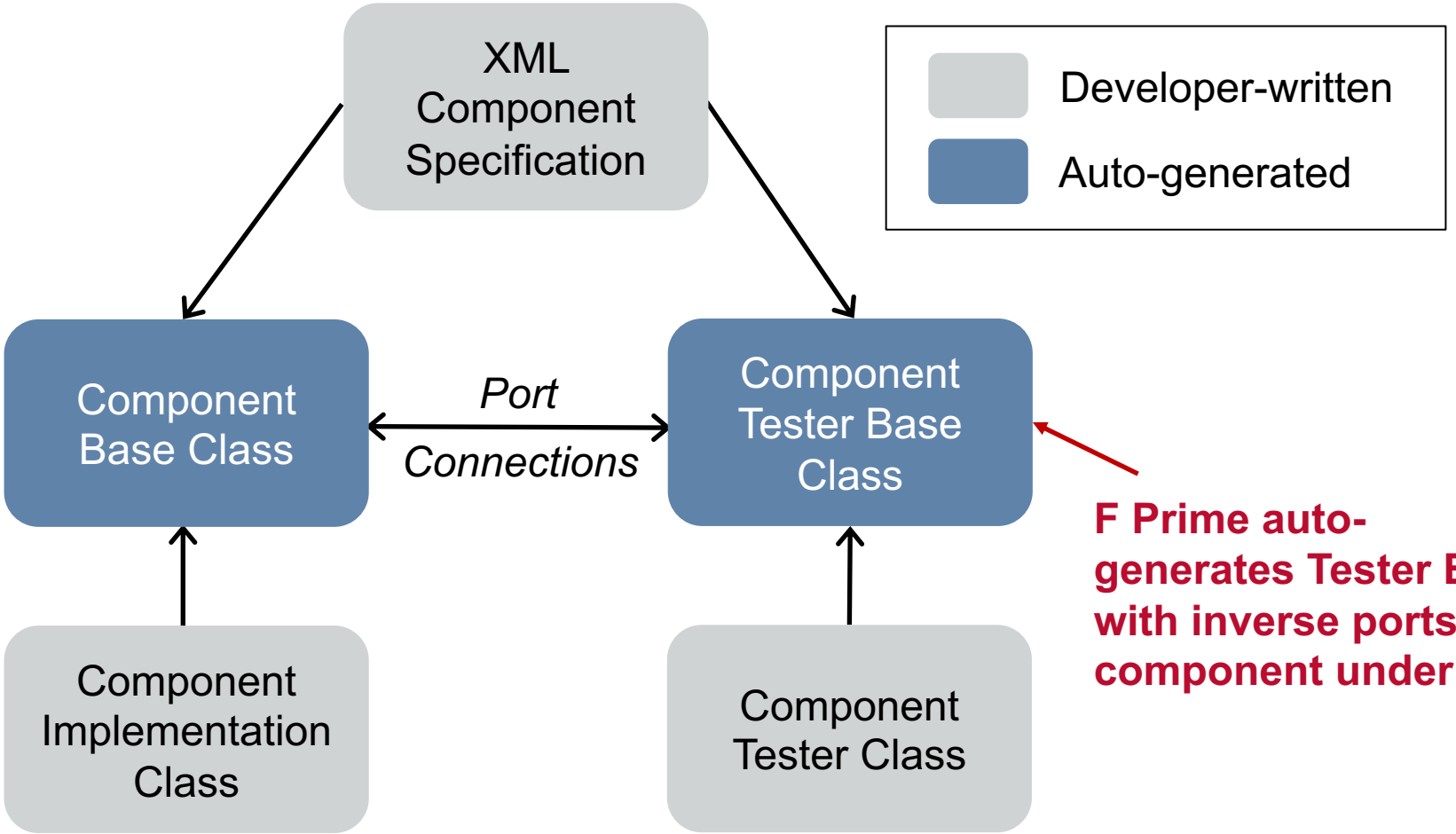
The F Prime FSW Framework

Reusable Components

- F Prime comes with over 20 reusable components (and counting)
- The components provide many standard FSW behaviors
  - Commanding
  - Events and telemetry
  - Ground interface
  - File system
  - Memory management
  - Generic data storage
  - Parameters (updatable constants)
  - Time
  - Health
  - Assertions and fatal events
- Fully unit-tested and ready to go

The F Prime FSW Framework

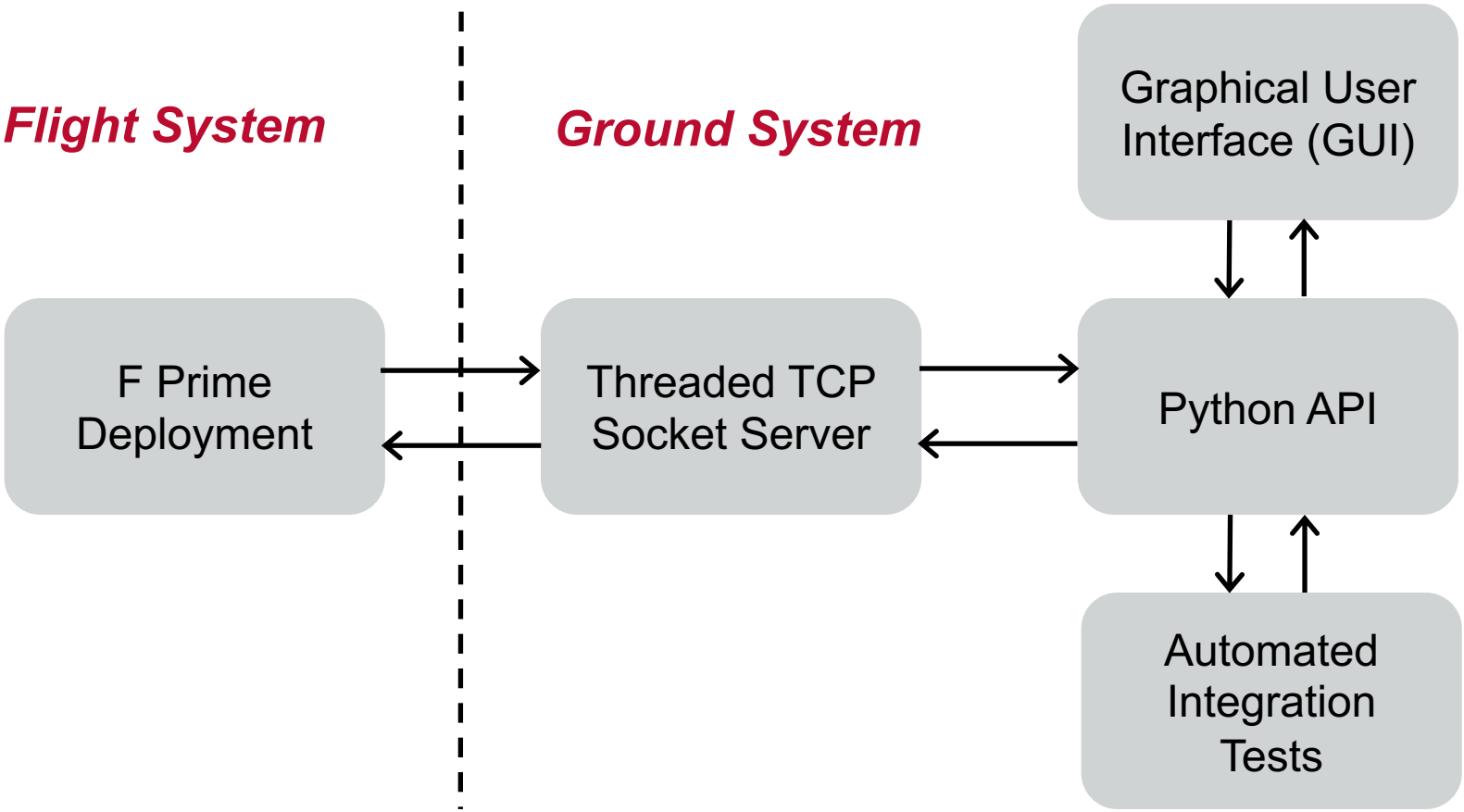
Unit Testing



Provides a simple solution for testing F Prime components

The F Prime FSW Framework

Ground Data System and Integration Testing

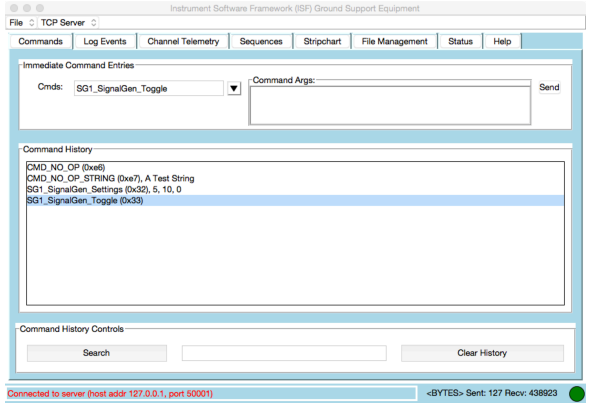


Provides a simple solution for testing F Prime deployments

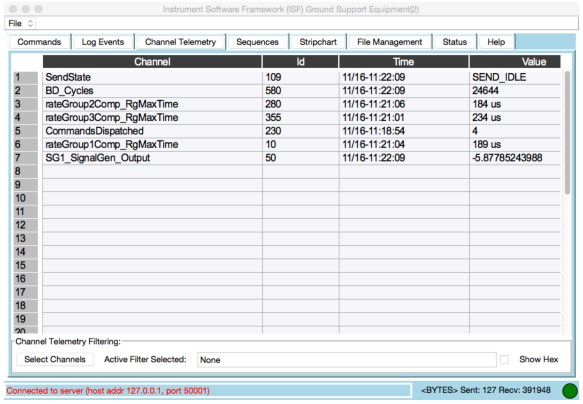
The F Prime FSW Framework

The Ground Data System GUI

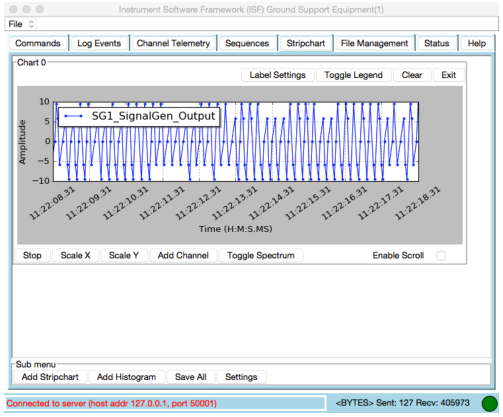
Commanding View



Telemetry View

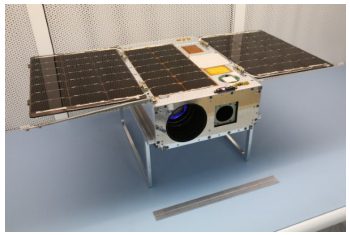


Strip Chart View



Experience with F Prime

Missions and Projects



- We have used F Prime on several space missions
  - **ISS RapidScat** scatterometer (flew)
  - **ASTERIA** CubeSat (flying now)
  - **Mars Helicopter** (in development)
  - **Lunar Flashlight** CubeSat (in development)
  - **Near Earth Asteroid (NEA) Scout** CubeSat (in development)
- We have used F Prime for research and education
  - JPL R&D project on autonomous FSW
  - Collaborations with several universities
- F Prime can reduce the cost of developing FSW
  - Facilitate sharing and reuse between projects
  - Let developers focus on mission-specific code

Enhancements in Progress

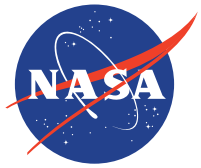
Making F Prime Better

- Modeling and code generation
  - New input language and visualizer for F Prime models
  - It will be free and easier to use than MagicDraw/SysML
- Testing of F Prime components
  - Tools for automatically picking test inputs
  - Tools for generating tests from high-level specifications
  - Integrated model checking with Spin
- Ground data system
  - XTCE ground dictionaries
  - Mobile user interface
  - Improved server using ZeroMQ

Conclusion

- Developing FSW for small spacecraft is hard
- F Prime can help
  - Architecture
  - Direct code reuse
  - Development ecosystem
- F Prime is a flight-proven technology
- Several enhancements are in progress

https://github.com/nasa/fprime



Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov